Large-Apertured Projection Lens With Minimal Diaphragm Error

Cross-Reference to Related Applications

~~Not applicable~~ This application is a Continuation of PCT application PCT/EP99/09235 filed November 27, 1999.

Statement Regarding Federally Sponsored Research or Development

Not applicable

Background of the Invention

[0001] The invention relates to a microlithographic projection lens, in which the system diaphragm is arranged in the region of the last bulge on the image side, and has a numerical aperture of more than 0.65 and an image field diameter of more than 20 mm. Such lenses are typically characterized by a resolution below 0.5 micrometers with minimal distortion and at least image-side telecentricity.

[0002] The microlithographic reduction lens of the category concerned is a microlithographic projection lens having a system diaphragm arranged in a region of a last bulge on an image side, and having an image-side numerical aperture of more than 0.65 and an image field diameter of more than 20 mm, and is a purely refractive high performance lens such as is required for high resolution microlithography, particularly in the DUV wavelength region.

Technical Field

[0003] Such refractive lenses with two beam waists have already been described in the article by E. Glatzel, "New Lenses for Microlithography", SPIE, Vol. 237, 310 (1980), and have been constantly developed since then. Lenses of the Carl Zeiss company of the category concerned are sold in PAS wafer steppers and wafer scanners of the ASML company, Netherlands.

[0004] Such a lens by the Tropel company dating from 1991 is shown in Fig. 16 of J.H. Bruning,

"Optical Lithography - Thirty Years and Three Orders of Magnitude", SPIE, Vol. 3049, 14-27 (1997). Numerous variants of projection lenses of the category concerned can be found in patent applications, such as EP 0 712 019-A (US Ser. No. 337,649 of November 10, 1994), EP 0 717 299-A, EP 0 721 150-A, EP 0 732 605-A, EP 0 770 895-A, EP 0 803 755-A (U.S. Patent 5,781,278), and EP 0 828 172-A.

[0005] Similar objectives with somewhat smaller numerical aperture are also to be found in SU 1 659 955-A, EP 0 742 492-A (Fig. 3), U.S. Patent 5,105,075 (Figs. 2 and 4), U.S Patent 5,260,832 (Fig. 9) and DD 299 017-A.

[0006] In the cited documents, the diaphragm of course has many different situations, in particular in the region of the second waist.

[0007] The possibility of stopping down to about 60-80% of the maximum image-side numerical aperture is as a rule provided in high-aperture microlithography projection lenses.

[0008] This possibility of stopping down is explicitly mentioned in DE 199 02 236 A1, which was first published after the priority date of the present application. In this, and also in DE 198 18 444 A1, the use of aspheric lenses is also provided, and indeed at least one aspheric in the region of the second waist (fourth lens group). The embodiments of Figs. 1-3 of the priority application DE 198 55 108.8 show a relatively strongly curved pupil plane with an axial offset of about 25 mm between the optical axis and the edge of the pencil of rays at full aperture. Correspondingly, expensive diaphragm structures are required for stopping down.

[0009] The priority applications DE 198 55 108.8, DE 198 55 157.6 and DE 199 22 209.6, DE 199 42 281.8, with their disclosures and including the claims, are incorporated herein by reference as part of the disclosure of the present patent application.

[0010] As "pupil plane" there is understood, in the sense of the present patent application, the curved surface of the pupil or, fourier transformed, of the image plane, as it is constituted real due to imaging errors of the lens arrangement. The edge of the aperture diaphragm of the system must lie on this surface if vignetting effects are to be prevented. If the real aperture diaphragm is made narrower and wider in a planar geometrical plane, the freedom from vignetting is approximately the better, the less the pupil plane departs from a planar surface.

Summary of the Invention

[0011] The invention has as its object the provision of lenses of the category concerned with well corrected pupils, making possible cleaner stopping down without disturbing effects and with a simple diaphragm structure.

[0012] This object is attained by a projection lens of the category concerned wherein a pupil plane is curved over a cross section of a pencil of rays by a maximum of 20 mm.

[0013] This object is also attained by a projection lens of the category concerned wherein the lens has a telecentricity deviation of less than ± 4 mrad, preferably less than ± 3 mrad of the geometric central beam, on stopping down to 0.8 times the image side numerical aperture. This object is also attained by a projection lens of the category concerned wherein a tangential image dishing of a pupil image in a diaphragm space is corrected to less than 20 mm, preferably less than 15 mm.

[0014] According to the invention, the pupil plane is curved by at most 20 mm, but preferably by less than 15 mm.

[0015] The image-side telecentricity is also well kept very stable, even when stopping down to 0.8 times the nominal (maximum) image-side numerical aperture; measured at the

geometrical central beam, it is below ± 4 mrad.

[0016] Since the image field curvature of the front or rear lens portion cannot be exactly corrected alone (or at all events not at a justifiable expense, since it can only be influenced by means of the distribution of refractive index), the image error compromise in the image plane is chosen so that the image field curvature is partially compensated by astigmatism (which can be adjusted by means of targeted lens curvature with unchanged refractive index), at least in the tangential imaging relevant for the diaphragm structure.

[0017] According to the invention, apart from the optical correction of the lens, the tangential image dishing of the pupil imaging in the diaphragm space is corrected to less than 20 mm. Imaging of the pupil plane is thus explicitly taken into account in the image error compromise of the lens.

[0018] A negative lens is required in the space behind the pupil plane for the correction of spherical aberration in projection lenses of the category concerned.

[0019] According to the invention, the pupil correction according to the invention is now attained with the presence of a pupil-side concave meniscus, and makes possible a good correction of all imaging errors. The flatter the diverging image-side radius of the negative lens, the more favorable this lens is for the pupil correction.

[0020] A diaphragm position according to the invention is clearly away from the second waist, and is also different from DE 199 02 336 A1 and from other documents of the prior art.

[0021] The beam deflection in this region of the third bulge with many weak positive lenses results in minimum spherical under-correction and thus makes possible weak negative lenses, which further relaxes the correction of the pupil plane. The variation of the image errors

when stopping down or at different illumination settings is further reduced as a whole by these measures.

[0022] The spherically over-correcting air space advantageously provided according to the invention and having a middle thickness greater than the edge thickness can be arranged in the neighborhood of the negative meniscus.

[0023] An aspheric lens is arranged in the region of the first waist. Aspherics in the region of the second waist can be dispensed with, while in the state of the art according to DE 199 02 336 A1 and DE 198 18 444 A1 they are to be arranged exactly there.

[0024] According to the invention, the material of the lenses is quartz glass and/or fluoride crystals, the lenses then becoming suitable for the DUV/VUV region, in particular at the wavelengths of 248 nm, 193 nm, and 157 nm. Fluoride crystals are CaF_2, BaF_2, SrF_2, NaF and LiF. Further information on this may be found in DE 199 08 544.

[0025] The projection lens according to the invention has two waists and three bulges, as in the embodiment examples. This makes possible a very good Petzval correction at exacting values of the aperture and field.

[0026] A projection illumination device with a lens according to the invention and a microlithographic production process therewith.

[0027] The possibility, optimized according to the invention, provides for the application of exposures with different kinds of illumination and/or numerical aperture.

Brief Description of the Drawings

[0028] The invention is described in more detail with the aid of the embodiment examples according to the drawing and the tables.

[0029] Fig. 1 shows qualitatively a projection exposure device according to the invention.

[0030] Fig. 2 shows the lens section of a 103 nm quartz glass/CaF$_2$ projection lens with NA = 0.70.

[0031] Fig. 3 shows the lens section through a second lens arrangement, which has two aspheric lens surfaces;

[0032] Fig. 4 shows the lens section through a third lens arrangement, which has three aspheric surfaces;

[0033] Figs. 5a-5g show a representation of tangential transverse aberrations;

[0034] Figs. 6a-6g show a representation of sagittal transverse aberrations;

[0035] Figs. 7a-7f show a representation of groove error, using sections;

[0036] Fig. 8 shows the lens section through a fourth lens arrangement for 248 nm with NA = 0.70.

Detailed Description of the Invention

[0037] The principle of the construction of a projection exposure device will first be described using Fig. 1. The projection exposure device 1 has an illuminating device 3 and a projection lens 5. The projection lens includes a lens arrangement 19 with an aperture diaphragm AP, an optical axis 7 being defined through the lens arrangement 19. A mask 9 is arranged between the illuminating device 3 and the projection lens 5, and is held in the beam path by a mask holder 11. Such masks 9 used in microlithography have a microstructure which is imaged on a reduced scale on an image plane 13 by means of the projection lens 5. A substrate or a wafer 15, positioned by a substrate holder 17, is held in the image plane 13.

[0038] This projection lens 5, and in particular its lens arrangement 19, designed for more

stringent requirements on image quality and on resolution, is described in more detail hereinafter.

[0039] The embodiment example according to Fig. 2 and Table 1 is a projection lens with purely spherical lenses, as a quartz glass/CaF$_2$ partial achromat for 193 nm excimer laser with 0.5 pm bandwidth. The image-side NA is 0.70; the image field diameter is 29.1 mm. The pupil plane with the aperture stop AS is situated far back from the second waist in the region of an intermediate constriction of the third bulge. Its curvature is 15.8 mm at a light pencil diameter of 212 mm.

[0040] For the determination of the curvature of the pupil plane, the tangential image shell of the pupil image in the diaphragm space is determined such that the axial amount of image deviation, produced between the image plane and the pupil plane by the lens portion, of a parallel beam passing at the aperture angle through the image field is determined as compared with the image of a parallel beam parallel to the axis. The not large sagittal value for stopping down and vignetting is 26.5 mm here, and thus shows the introduced astigmatism.

[0041] With stopping down to NA = 0.56, the lens shows a deviation from telecentricity of the geometric central beam of 3 mrad.

[0042] It would be particularly valuable to design this lens arrangement for a small diameter of the CaF$_2$ lenses, since their availability is restricted.

[0043] The examples of Figs. 3 and 4 have aspherics. These aspheric surfaces are described by the equation

$$P(h) = \frac{\delta * h^2}{1 + \sqrt{1-(1-EX) * \delta^2 * h^2}} + C1\, h^4 + \ldots + C_n\, h^{2n-2} \qquad \text{with } \delta = 1/R$$

where P is the arrow height as a function of the radius h (height from the optical axis 7) with the

aspheric constants C_1-C_n given in the Tables. R is the vertex radius given in the Tables.

[0044] In Fig. 3 and Table 2, a quartz glass lens arrangement 19 designed for the wavelength λ =

248 nm is shown in section. This lens arrangement 19 with NA = 0.75 and image field

diameter 27.2 mm has two aspheric lens surfaces 27, 29. The first aspheric lens surface 27 is

arranged on the image side on the lens L210. It could also be provided that this second

aspheric lens surface 29 is arranged on the side of the lens L211 facing toward the illuminat-

ing device. The two lenses L210 and L211 are predetermined to receive the aspheric lens

surface 27. It can also be provided that a meniscus lens is provided instead of the lenses

L210 and L211, and has an aspheric lens surface. The second aspheric lens surface 29 is

arranged in the end region of the first lens group, on the side of the lens L205 remote from

the illuminating device 8. It can also be provided that this aspheric lens surface 29 is

arranged on the lens 206 following thereafter, in the beginning of the second lens group.

[0045] A particularly large effect is obtained on arranging the asphercis 27, 29 on lens surfaces at

which the incident rays include a large angle with the respective surface normals. In this

case, it is particularly the large variation of the angle of incidence which is of importance. In

Fig. 10, the value of sin i at the aspheric lens surface 31 reaches a value of up to 0.82. As a

result of this, the mutually facing surfaces of the lenses L210, L211 have in this embodiment

example a greater influence on the course of the rays in comparison to the respective other

lens surface of the corresponding lens L210, L211.

[0046] No aspheric is provided in the region of the second waist, lens group LG4.

[0047] With a length of 1,000 mm and a maximum lens diameter of 237.5 mm, this lens arrangement has a numerical aperture of 0.75 at a wavelength of 248.38 nm. The image field diagonal is 27.21 mm. A structure width of 0.15 μm can be resolved. The greatest deviation from the ideal wavefront is 13.0 mλ. The exact lens data with which these performance data are attained are given in Table 2.

[0048] The pupil plane intersects the optical axis at AP. Its curvature is 12.8 mm. A stopping down to NA = 0.60 is possible without loss of quality with a diaphragm situated in the plane AP. The deviation from telecentricity of the geometric central beam is then about 1.5 mrad.

[0049] A further embodiment of a lens arrangement 19 for the wavelength 248.38 nm is shown in Fig. 4 and Table 3. With an image-side NA = 0.77, the image field diameter is 27.2 mm.

[0050] This lens arrangement 19 has three lenses L305, L310, L328, which have respective aspheric surfaces 27, 29, 31. The aspheric lens surfaces 27, 29 are left in the positions given by Fig. 3. The coma of middle order for the image field zone can be adjusted by means of the aspheric lens surface 27. The repercussions on sections in the tangential direction and sagittal direction are small.

[0051] The additional aspheric lens surface 31 is arranged on the mask side on the lens L328. This aspheric lens surface 31 supports the coma correction to the image field edge.

[0052] By means of these three aspheric lens surfaces 27, 29, 31, at a wavelength of 248.34 nm, a length of only 1,000 mm, and a maximum lens diameter of 247.2 mm, there are attained the further increased numerical aperture of 0.77 and a structure width of 0.14 μm which can be well resolved in the whole image field. The maximum deviation from the ideal wavefront is 12.0 mλ.

[0053] In order to keep the diameter of the lenses in LG5 small, and in order for an advantageous Petzval sum, which is to be kept at nearly zero, for the system, the three lenses L312, L313, L314 are enlarged in the third lens group LG3. For the provision of the required axial constructional space for these three lenses L312-L314, the thicknesses, and hence the diameter, of other lenses are reduced, particularly of the lenses of the first group LG1. This is an excellent way to accommodate very large image fields and apertures in a restricted constructional space.

[0054] The high image quality attained by this lens arrangement is to be gathered from Figs. 5a-5g, Figs. 6a-6g, and Figs. 7a-7f.

[0055] Figs. 5a-5g give the meridional transverse aberrations DYM for the image heights Y' (in mm). All show an outstanding course up to the highest DW'.

[0056] Figs. 6a-6g give the sagittal transverse aberrations DZS as a function of the half aperture angle DW'.

[0057] Figs. 7a-7f give the groove error DYS for the same image heights; it is nearly zero throughout.

[0058] The exact lens data can be gathered from Table 3; the aspheric lens surfaces 27, 29, 31 have a considerable contribution to the high image quality which can be guaranteed.

[0059] The curvature of the pupil plane AP amounts to 14.6 mm at full aperture. The deviation from telecentricity on stopping down to NA = 0.62 is 1.5 mrad, determined as in the preceding examples.

[0060] A further lens arrangement for the wavelength 248 nm is shown in Fig. 8 and Table 4.

[0061] This example is furthermore constructed purely spherically. It is particularly designed so

that the distortion and the further imaging errors remain minimal with substantial stopping down, even with different kinds of illumination (different degree of coherence, annular aperture illumination, quadrupole illumination). The pupil plane is corrected to a curvature of 18.5 mm at full aperture.

[0062] Also it comes about here that the curved image of the pupil was substantially compensated by targeted correction of the astigmatism in the tangential section.

[0063] The air lens between the lenses 623, 624, the splitting of the negative meniscus into two lenses 624, 625, and the position of the pupil plane at AS markedly separated by two positive lenses from the second waist (617), contribute to its leveling.

[0064] In a high-aperture projection lens for microlithography, the diaphragm errors are accordingly systematically corrected, so that an only slightly curved pupil plane makes stopping down possible without a loss of quality.

As already mentioned, the embodiment examples are not limitative for the subject of the invention.

Abstract of the Disclosure

The invention relates to a large-apertured microlithography projection lens. The diaphragm error is also systematically corrected, so that the pupil plane is slightly curved and the lens can be stopped down without comprising quality. The system diaphragm of the projection lens is located in the area of the last lens cluster of positive refractive power on the image side. The telecentrics of the projection lens remain stable on the image side during stopping down.

Table 1

λ= (193 nm)

| No.	r (mm)	d (mm)	Glass	H_{max} (mm)
0	∞	15.691		64
21	-154.467	11.998	SiO₂	64
	446.437	12.272		73
22	-723.377	25.894	SiO₂	74
	-222.214	.824		80
23	920.409	26.326	SiO₂	89
	-287.371	.750		90
24	499.378	30.073	SiO₂	94
	-358.998	.751		94
25	238.455	27.454	SiO₂	90
	-3670.974	.750		89
26	182.368	13.402	SiO₂	81
	115.264	31.874		72
27	-710.373	13.095	SiO₂	72
	-317.933	2.550		71
28	-412.488	8.415	SiO₂	69
	132.829	32.913		65
29	-184.651	11.023	SiO₂	66
	2083.916	28.650		71
30	-120.436	10.736	SiO₂	72
	-629.160	16.486		86
31	-213.698	24.772	SiO₂	89
	-151.953	.769		95
32	11013.497	48.332	SiO₂	115
	-202.880	.750		118
33	-1087.551	22.650	SiO₂	122
	-483.179	.750		124
34	1797.628	23.724	SiO₂	125
	-1285.887	.751		125
35	662.023	23.589	SiO₂	124
	45816.292	.750		123
36	361.131	22.299	SiO₂	119
	953.989	.750		117
37	156.499	49.720	CaF₂	107
	2938.462	.154		103
38	377.619	8.428	SiO₂	94
	123.293	40.098		80
39	-425.236	10.189	SiO₂	78
	413.304	18.201		74
40	-302.456	6.943	SiO₂	73
	190.182	46.542		73
41	-109.726	9.022	SiO₂	73
	-1968.186	5.547		89
42	-7658.656	37.334	CaF₂	90
	-146.709	.753		94
43	925.552	49.401	CaF₂	108
	-193.743	.847		109
44	507.720	22.716	CaF₂	105
	-1447.522	21.609		104
45	-250.873	11.263	SiO₂	104
	314.449	2.194		105
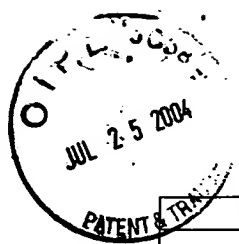
Table 1 (continued)

46	316.810	28.459	CaF$_2$	106
	-1630.246	4.050		106
AS	Diaphragm	15.000		106
47	312.019	45.834	CaF$_2$	108
	-38855.881	11.447		108
48	-242.068	14.119	SiO$_2$	107
	312.165	4.687		112
49	327.322	49.332	SiO$_2$	114
	-372.447	14.727		115
50	-234.201	26.250	SiO$_2$	115
	-226.616	.850		118
51	203.673	45.914	SiO$_2$	113
	-3565.135	.751		111
52	157.993	29.879	SiO$_2$	94
	431.905	14.136		90
53	-1625.593	12.195	SiO$_2$	88
	230.390	.780		76
54	124.286	66.404	SiO$_2$	71
	538.229	1.809		46
55	778.631	4.962	CaF$_2$	45
	43.846	2.050		34
56	43.315	23.688	CaF$_2$	33
	1056.655	2.047		29
P2	∞	2.000	CaF$_2$	27
	∞	12.000		26
IM	∞			14

Image-side numerical aperture 0.75   Image field diameter 29 mm
Lenses 37 of which CaF$_2$ 5
Chromatic longitudinal error   CHL (500 pm) = 0.15 mm
Chromatic transverse error   CHV (500 pm) = -0.55 mm

Table 2

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Lens	Radius	Thickness	Glasses	½ lens diameter
	infinity	16.6148		60.752
L201	-140.92104	7.0000	SiO2	61.267
	-4944.48962	4.5190		67.230
L202	-985.90856	16.4036	SiO2	68.409
	-191.79393	.7500		70.127
L203	18376.81346	16.5880	SiO2	73.993
	-262.28779	.7500		74.959
L204	417.82018	21.1310	SiO2	77.129
	-356.76055	.7500		77.193
L205	185.38468	23.3034	SiO2	74.782
	-1198.61550	A7500		73.634
L206	192.13950	11.8744	SiO2	68.213
	101.15610	27.6353		61.022
L207	-404.17514	7.0000	SiO2	60.533
	129.70591	24.1893		58.732
L208	-235.98146	7.0584	SiO2	59.144
	-203.88450	.7500		60.201
L209	-241.72595	7.0000	SiO2	60.490
	196.25453	33.3115		65.017
L210	-122.14995	7.0000	SiO2	66.412
	-454.65265	A 10.8840		77.783
L211	-263.01247	22.6024	SiO2	81.685
	-149.71102	1.6818		86.708
L212	-23862.31899	43.2680	SiO2	104.023
	-166.87798	.7500		106.012
L213	340.37670	44.9408	SiO2	115.503
	-355.50943	.7500		115.398
L214	160.11879	41.8646	SiO2	102.982
	4450.50491	.7500		100.763
L215	172.51429	14.8261	SiO2	85.869
	116.88490	35.9100		74.187
L216	-395.46894	7.0000	SiO2	72.771
	178.01469	28.0010		66.083
L217	-176.03301	7.0000	SiO2	65.613
	188.41213	36.7224		66.293
L218	-112.43820	7.0059	SiO2	66.917
	683.42330	17.1440		80.240
L219	-350.01763	19.1569	SiO2	82.329
	-194.58551	.7514		87.159
L220	-8249.50149	35.3656	SiO2	99.995
	-213.88820	.7500		103.494
L221	657.56358	31.3375	SiO2	114.555
	-428.74102	.0000		115.245
	infinity	2.8420		116.016
	diaphragm	.0000		116.016
L222	820.30582	27.7457	SiO2	118.196
	-520.84842	18.4284		118.605
L223	330.19065	37.7586	SiO2	118.273
	-672.92481	23.8692		117.550
L224	-233.67936	10.0000	SiO2	116.625
	-538.42627	10.4141		117.109

Table 2 (continued)

L225	-340.26626	21.8583	SiO2	116.879
	~~436.70958~~ 224.85666	.7500		117.492
L226	146.87143	34.5675	SiO2	100.303
	~~-224.85666~~ 436.70958	.7500		97.643
L227	135.52861	29.8244	SiO2	86.066
	284.57463	18.9234		79.427
L228	-7197.04545	11.8089	SiO2	72.964
	268.01973	.7500		63.351
L229	100.56453	27.8623	SiO2	56.628
	43.02551	2.0994		36.612
L230	42.30652	~~63.9541~~ 30.9541	SiO2	36.023
	262.65551	1.9528		28.009
	Infinity	12.0000		27.482
	Infinity			13.602

Aspheric Constants

Coefficients of aspheric surface 29:

$EX = -0.17337407 * 10^3$
$C\,1 = 0.15292522 * 10^{-7}$
$C\,2 = 0.18756271 * 10^{-11}$
$C\,3 = -0.40702561 * 10^{-16}$
$C\,4 = 0.26176919 * 10^{-19}$
$C\,5 = -0.36300252 * 10^{-23}$
$C\,6 = 0.42405765 * 10^{-27}$

Coefficients of aspheric surface 27:

$EX = -0.36949981 * 10^1$
$C\,1 = 0.20355563 * 10^{-7}$
$C\,2 = -0.22884234 * 10^{-11}$
$C\,3 = -0.23852614 * 10^{-16}$
$C\,4 = -0.19091022 * 10^{-19}$
$C\,5 = 0.27737562 * 10^{-23}$
$C\,6 = -0.29709625 * 10^{-27}$

Table 3

Lens	Radius	Thickness	Glasses	½ lens diameter
	Infinity	17.8520		60.958
L301	-131.57692	7.0000	SiO$_2$	61.490
	-195.66940	.7500		64.933
L302	-254.66366	8.4334	SiO$_2$	65.844
	-201.64480	.7500		67.386
L303	-775.65764	14.0058	SiO$_2$	69.629
	-220.44596	.7500		70.678
L304	569.58638	18.8956	SiO$_2$	72.689
	-308.25184	.7500		72.876
L305	202.68033	20.7802	SiO$_2$	71.232
	-1120.20883	A7500		70.282
L306	203.03395	12.1137	SiO$_2$	65.974
	102.61512	26.3989		59.566
L307	-372.05336	7.0000	SiO$_2$	59.203
	144.40889	23.3866		58.326
L308	-207.93626	7.0303	SiO$_2$	58.790
	-184.65938	.7500		59.985
L309	-201.97720	7.0000	SiO$_2$	60.229
	214.57715	33.1495		65.721
L310	-121.80702	7.0411	SiO$_2$	67.235
	-398.26353	A 9.7571		79.043
L311	-242.40314	22.4966	SiO$_2$	81.995
	-146.76339	.7553		87.352
L312	-2729.19964	45.3237	SiO$_2$	104.995
	-158.37001	.7762		107.211
L313	356.37642	52.1448	SiO$_2$	118.570
	-341.95165	1.1921		118.519
L314	159.83842	44.6278	SiO$_2$	105.627
	2234.73586	.7698		102.722
L315	172.14697	16.8960	SiO$_2$	88.037
	119.53455	36.6804		75.665
L316	-392.62196	7.0000	SiO$_2$	74.246
	171.18767	29.4986		67.272
L317	-176.75022	7.0000	SiO$_2$	66.843
	186.50720	38.4360		67.938
L318	-113.94008	7.0213	SiO$_2$	68.650
	893.30270	17.7406		82.870
L319	-327.77804	18.9809	SiO$_2$	85.090
	-192.72640	.7513		89.918
L320	-3571.89972	34.3608	SiO$_2$	103.882
	-209.35555	.7500		106.573
L321	676.38083	632.6220	SiO$_2$	119.191
	-449.16650	.0000		119.960
	Infinity	2.8420		120.991
	Diaphragm	.0000		120.991
L322	771.53843	30.6490	SiO$_2$	123.568
	-525.59771	13.4504		124.005
L323	330.53202	40.0766	SiO$_2$	123.477
	-712.47666	23.6787		122.707
L324	-250.00950	10.0000	SiO$_2$	121.877
	-513.10270	14.8392		121.995
L325	-344.63359	20.3738	SiO$_2$	121.081
	-239.53067	.7500		121.530

Table 3 (continued)

L326	146.13385	34.7977	SiO₂	102.544
	399.32557	.7510		99.992
L327	132.97289	29.7786	SiO₂	87.699
	294.53397	18.8859		82.024
L328	-3521.27938	A 11.4951	SiO₂	75.848
	287.11066	.7814		65.798
L329	103.24804	27.8602	SiO₂	58.287
	41.64286	1.9089		36.734
L330	41.28081	31.0202	SiO₂	36.281
	279.03201	1.9528		28.934
	infinity	12.0000		28.382
	infinity			13.603

Aspheric Constants

Coefficients of aspheric surface 29:

$EX = -0.16784093 * 10^3$
$C\,1 = 0.49600479 * 10^{-9}$
$C\,2 = 0.31354487 * 10^{-11}$
$C\,3 = -0.65827200 * 10^{-16}$
$C\,4 = 0.44673095 * 10^{-19}$
$C\,5 = -0.73057048 * 10^{-23}$
$C\,6 = 0.91524489 * 10^{-27}$

Coefficients of aspheric surface 27:

$EX = -0.22247325 * 10^1$
$C\,1 = 0.24479896 * 10^{-7}$
$C\,2 = -0.22713172 * 10^{-11}$
$C\,3 = 0.36324126 * 10^{-16}$
$C\,4 = -0.17823969 * 10^{-19}$
$C\,5 = 0.26799048 * 10^{-23}$
$C\,6 = -0.27403392 * 10^{-27}$

Coefficients of aspheric surface 31:

$EX = 0$
$C\,1 = -0.45136584 * 10^{-09}$
$C\,2 = 0.34745936 * 10^{-12}$
$C\,3 = 0.11805250 * 10^{-17}$
$C\,4 = -0.87762405 * 10^{-21}$

Table 4

No.	r (mm)	d (mm)	Glass
0b		36.005	
601	-1823.618	15.518	Quartz Glass
	-214.169	10.000	
602	-134.291	7.959	Quartz Glass
	328.009	6.376	
603	783.388	26.523	Quartz Glass
	-163.805	.600	
604	325.109	20.797	Quartz Glass
	-499.168	1.554	
605	224.560	24.840	Quartz Glass
	-403.777	.600	
606	142.336	9.000	Quartz Glass
	86.765	23.991	
607	6387.721	7.700	Quartz Glass
	148.713	21.860	
608	-185.678	8.702	Quartz Glass
	237.204	30.008	
609	-104.297	9.327	Quartz Glass
	-1975.424	12.221	
610	-247.819	17.715	Quartz Glass
	-152.409	.605	
611	1278.476	40.457	Quartz Glass
	-163.350	.778	
612	697.475	28.012	Quartz Glass
	-346.153	2.152	
613	232.015	28.068	Quartz Glass
	-3080.194	2.606	
614	219.153	21.134	Quartz Glass
	434.184	9.007	
615	155.091	13.742	Quartz Glass
	103.553	34.406	
616	-207.801	8.900	Quartz Glass
	131.833	35.789	
617	-118.245	9.299	Quartz Glass
	1262.191	27.280	
618	-121.674	42.860	Quartz Glass
	-151.749	.825	
619	-366.282	20.128	Quartz Glass
	-236.249	.838	
620	2355.228	31.331	Quartz Glass
	-296.219	2.500	
P61	∞	6.000	Quartz Glass
	∞	12.554	
AS			
621	774.283	29.041	Quartz Glass
	-782.899	.671	
622	456.969	28.257	Quartz Glass
	-1483.609	.603	
623	227.145	30.951	Quartz Glass
	658.547	36.122	
624	-271.535	15.659	Quartz Glass
	-997.381	4.388	

Table 4 (continued)

625	-1479.857	27.590	Quartz Glass
	-288.684	.604	
626	259.988	22.958	Quartz Glass
	1614.379	.600	
627	105.026	29.360	Quartz Glass
	205.658	.600	
628	110.916	16.573	Quartz Glass
	139.712	13.012	
629	499.538	8.300	Quartz Glass
	56.675	9.260	
630	75.908	17.815	Quartz Glass
	51.831	.995	
631	43.727	19.096	Quartz Glass
	499.293	2.954	
P62	∞	2.000	Quartz Glass
	∞	12.000	
Im			